

Neutral pion number fluctuations

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Neutral pion number fluctuations have been measured in proton interactions at U-70 accelerator (IHEP, Protvino). The experiment is carried out on the SVD-2 setup. Charged and neutral particles are registered simultaneously. The reconstruction of π^0 -mesons is fulfilled by means of observed gamma quanta at the electromagnetic calorimeter. The corrections on the setup acceptance, triggering, efficiencies of detectors and the reconstruction algorithm are included. The multiplicity distributions of the neutral pions have permitted to define the scaled variance, ω , for π^0 -mesons. The revealed sharp growth of fluctuations of the neutral pion number at total meson multiplicities more than 22 can indicate the Bose-Einstein condensate formation.

Subject Index: 169, 322, 600

§1. Introduction

The Thermalization project is aimed at studying of pp and pA interactions at U-70 accelerator of IHEP (Protvino, Russia).¹⁾ The incident proton beam has energy 50 GeV. The experiment is carried out at SVD-2 (Spectrometer with Vertex Detector) setup. We study events with multiplicity significantly higher than mean one. Kinematical limit is equal to 57 pions at 50 GeV energy. The main purpose of our project is the search for collective phenomena at high multiplicity region of charged and neutral particles. We expect to reveal the following phenomena: Bose-Einstein condensation of pions,²⁾ peak structure at an angular distributions connecting with Cherenkov radiation³⁾ or shock wave formation,⁴⁾ the anomaly soft photon yield⁵⁾ and others.

The phenomenon of Bose-Einstein condensation (BEC) was predicted a long time ago. BEC is a unique phase transition, it occurs in the absence of interactions. Pions are the lightest hadrons and copiously produced at high energy. M.I. Gorenstein and V. V. Begun have proposed to search for BEC in system with high pion number.²⁾ They consider that the increasing of the total multiplicity of pions leads to decreasing of their energy, and the system can to drop out to condensate. It can be achieved by selecting the samples of events with high pion number. In accordance with their approach the scaled variance, ω^0 (ratio of variance, D , to the mean multiplicity of neutral pions, $\langle N_0 \rangle$, at given total multiplicity), can indicate BEC formation: close to the vicinity of the BEC point an abrupt and anomalous increase of $\omega^{02),7)}$ is expected.

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§2. Event selection, track fitting and correction procedure

The basic elements of SVD-2 setup are the liquid hydrogen target, precision microstrip silicon vertex detector (PVD), straw tube chambers, magnetic spectrometer consisted of proportional chambers and magnet, Cherenkov counter and electromagnetic calorimeter (ECal).¹⁾

PVD is one of the most important elements of SVD-2 setup permitted to determine vertex of interaction position and to reconstruct the charged particle tracks. It consists of 10 silicon planes and has more than 10000 registration channels. Thank to this detector the charged multiplicity is defined.

To select the high charged multiplicity events and to suppress considerably the low multiplicity event registration the scintillator hodoscope or high multiplicity trigger (HMT) have been manufactured.⁸⁾ This trigger does not distort events owing to its small thickness. Nuclear interactions in the trigger hodoscope are the source of noise in determining the event multiplicity. After applying additional criterium to trigger conditions the fraction of events with interactions in the trigger hodoscope did not exceed 4%.

The topological cross sections have been defined by using of the beam telescope and PVD information.⁹⁾ The 5.13 millions of 2008 year run events have been selected. From this statistics 3.85 millions of events have been taken at trigger-level 8 (lower limit of the registered multiplicity set at trigger system). Out of them 2.1 millions of events have been detected in the fiducial volume of the hydrogen target. For final analysis almost 1.0 million of events have been remained. They were selected according to the criterions: a) the number of beam tracks simultaneously hitting the target is not exceed 2 and b) the coordinates of the vertex on two projections is differed smaller than 5 mm.

The correction procedure of the charged particle number was carried out with taking into account an influence of the multiplicity trigger conditions, an acceptance of PVD, an efficiencies of track reconstruction algorithm and functioning of setup elements. We have added 4 new points (charged multiplicity from 18 up to 24) to the previously published Mirabelle data.¹⁰⁾ The cross section at the last point, $N_{ch}=24$, is three order of magnitude lower than it was at $N_{ch} = 16$.¹⁰⁾ Also we have made more precise the inelastic cross section, $\sigma(N_{ch})=31.50 \pm 1.14$ (stat) (mb), the mean charged multiplicity, $\langle N_{ch} \rangle=5.45 \pm 0.24$ (stat), the variance, $D=7.21 \pm 2.80$ (stat). The comparison with gluon dominance model¹¹⁾ shows the good agreement with data.⁹⁾ The negative binomial distribution¹²⁾ overestimates our data in high multiplicity area.

§3. Neutral pion number fluctuations

3.1. The simulation of the π^0 - meson detection

ECal permits to restore neutral pion multiplicity. Owing to restricted aperture of ECal and the lower energy threshold of the quantum registration, it is impossible to reconstruct all neutral pions in the each selected event. We have developed methods

of the π^0 reconstruction.¹³⁾ The simulation of neutral meson production, their decay and the registration of γ -quanta has been carried out. The linear dependence between mean number of π^0 -mesons, $\langle N_0 \rangle$, and the number of the registered photons, N_γ , have been established (Fig.1, Left) for charged multiplicity $N_{ch} \leq 14$. Although this dependence, $\langle N_0(N_\gamma) \rangle$, have been determined in the region $N_\gamma < 14$, we assumed it holds up to $N_\gamma \leq 24$ where our data are available.

MC code PYTHIA5.6 has shown value ω for γ -quanta falls down and remains constant for π^0 mesons at all available domain of total multiplicity ($N_{tot} \leq 24$).

3.2. Registration of γ -quanta and recovery of neutral pion number

ECal consists of 1344 lead glass detected elements with PMT. Almost all energy of the electromagnetic shower from γ -quantum hit into the center of element is dissipated in the cell consisted of 3×3 elements. ECal was calibrated by electron beam. The threshold energy of photon registration is equal to 100 MeV.

Majority of photons originate from the neutral pion decays. In each event the number of detected photons, N_γ , depends on the neutral pion number, N_0 . It can vary in the limits $(N_\gamma/2, 2 \times N_\gamma)$. We have solved the inverse task: the neutral pion multiplicity recovery by using the detected photon multiplicity.¹³⁾

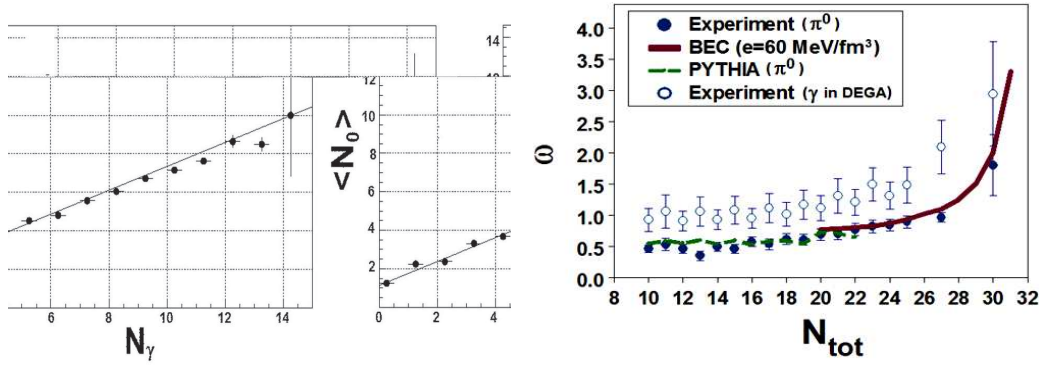


Fig. 1. Left: The mean neutral pion multiplicity versus the photon number detected in ECal.¹³⁾ Right: The measured scaled variance, ω , versus N_{tot} for π^0 -mesons (\bullet), photons (\circ), MC code PYTHIA (the dashed curve) and theoretical prediction (solid curve)²⁾ for $\epsilon = 60$ MeV/fm³. The data in the two interval with low statistics are combined.

As result we determine total multiplicity, neutral multiplicity distributions and scaled variance for neutral mesons versus total multiplicity.

At present the maximal number of reconstructed neutral mesons in the investigated area is equal to $N_0 = 24$ at $N_{ch} = 12$ (max observed total multiplicity is equal to 36). The known ratio between charged and neutral mesons (2:1) in these events is broken down. The estimations show the mean energy of pion is equal to 75 MeV with such multiplicity in c.m.s. In accordance with quantum statistics this energy is comparable to the critical energy of BEC.¹⁴⁾

The scaled multiplicity is used ($n_0 = N_0/N_{tot}$) for analysis of data. This variable n_0 is convenient for the comparison of distributions at different total multiplicities. The scaled multiplicity distribution is fitted by Gaussian to define $\langle N_0 \rangle$

and variance. In Fig.1 (Right) the scaled variances for neutral particles are presented: experimental values for mesons and photons, the predictions from MC code PYTHIA and the theoretical estimation²⁾ for mean energy density $\epsilon = 60 \text{ MeV/fm}^3$. Our experimental data can evidence the Bose-Einstein condensate formation in pion system in pp -interactions at 50 GeV. Thus neutral pion number fluctuations increase at $N_{tot} > 22$, that can indicate approaching to BEC for the high multiplicity pion system. This behavior has been observed for the first time.

One of possible explanation of excess of soft photon yield in hadron interactions was suggested by S. Barshay.¹⁵⁾ He considers BEC leads to cold pion fireball formation which can radiate soft photons with $p_T < 50 \text{ MeV}$. Our future plans are aimed at the manufacture of ECal and the study of soft photon yield versus charged as neutral multiplicities.

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